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Towards a different attitude to uncertainty

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Abstract

The ecological literature deals with uncertainty primarily from the perspective of how to reduce it to acceptable levels. However, the current rapid and ubiquitous environmental changes, as well as anticipated rates of change, pose novel conditions and complex dynamics due to which many sources of uncertainty are difficult or even impossible to reduce. These include both uncertainty in knowledge (epistemic uncertainty) and societal responses to it. Under these conditions, an increasing number of studies ask how one can deal with uncertainty as it is. Here, we explore the question how to adopt an overall alternative attitude to uncertainty, which accepts or even embraces it. First, we show that seeking to reduce uncertainty may be counterproductive under some circumstances. It may yield overconfidence, ignoring early warning signs, policy- and societal stagnation, or irresponsible behaviour if personal certainty is offered by externalization of environmental costs. We then demonstrate that uncertainty can have positive impacts by driving improvements in knowledge, promoting cautious action, contributing to keeping societies flexible and adaptable, enhancing awareness, support and involvement of the public in nature conservation, and enhancing cooperation and communication. We discuss the risks of employing a certainty paradigm on uncertain knowledge, the potential benefits of adopting an alternative attitude to uncertainty, and the need to implement such an attitude across scales – from adaptive management at the local scale, to the evolving Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) at the global level.

Keywords

Biodiversity conservation, communication, externalization, adaptive management, risk management, policy inaction, science-policy dialogue, IPBES

Introduction

The rapid growth in human population, combined with a steep increase in resource- and energy-demands, exert unprecedented pressures on Earth's natural resources (Rockstrom et al. 2009). Natural and semi-natural habitats continue being rapidly converted or degraded in response to humanity's growing needs. These rapid changes raise uncertainties about the future of biodiversity, ecosystem functioning and services. Additional sources of uncertainty emerge from rapid social, economic, political, and technological changes (to name just a few). The conservation of biodiversity is thus subject to an exceptional range of challenges and sources of uncertainty.

The topic of uncertainty in biodiversity research and conservation practice has traditionally focused on the realms of knowledge, also referred to as epistemic uncertainty (Regan et al. 2002). The literature often focuses on three main origins of such uncertainty: i) data, ii) models and iii) predictions - as well as their propagation along the scientific process (e.g. Regan et al. 2002; Burgman et al. 2005; Sutherland 2006; McDonald-Madden et al. 2010; Conroy et al. 2011; Polasky et al. 2011; Beale and Lennon 2012; Evans 2012). Important distinctions were made between imperfect knowledge (Funtowicz and Ravetz 1991) and inherent, or ontological uncertainty, due to stochasticity or randomness (Regan et al. 2002; Evans 2012; Haila and Henle 2014). Yet, the literature is very limited in consideration of other sources of uncertainty (Funtowicz and Ravetz 1991; Regan et al. 2002; Smith 2007; Mitchell 2009; Haila and Henle 2014). Particularly, sources of uncertainty pertaining to the "societal sphere" (as opposed to the "knowledge sphere") have received little attention. They emerge as soon as knowledge has to be transferred, translated, shared, and implemented in the decision-making process (Ibisch et al. 2012). For instance, linguistic uncertainty emerging from vagueness and ambiguity can add confusion independently of epistemic uncertainty (Regan et al. 2002). Additionally, uncertainty may originate from societal response, ranging from social vindication to public consent, scepticism, or rejection.

It is important to realize that all dimensions of uncertainty strongly interact: subjective judgements surrounding the knowledge sphere are shaped by uncertainty levels belonging to cognitive processes (i.e. pre-conceptual (data), conceptual (proxy) or symbolic levels (concepts) (Gärdenfors 2004; Haila and Henle 2014)). Ultimately, uncertainty arising from the societal context affects decision-making (Marzetti and Scazzieri 2011), and human preferences or fickleness create complex feedbacks among the components of socio-ecological systems (Levin 1999; Francis and Goodman 2010).

Traditional approaches focusing mostly on reducing (epistemic) uncertainty, e.g. through narrowing it within frequencies and quantity intervals or gathering further evidence, are likely to be insufficient (Sutherland 2006; Conroy et al. 2011; Evans 2012). Besides, some aspects of uncertainty remain intrinsically irreducible (e.g. "unknowables"; Ibisch et al. 2012). Discussions conducted within two workshops on the topic of uncertainty in biodiversity conservation, held in November and December 2011 in Leipzig, Germany, identified three alternative approaches to dealing with uncertainty: reducing it, accepting it, or embracing it (Haila et al. 2014). In accordance with these

discussions, here we seek to explore how accepting and embracing uncertainty can promote progress in biodiversity research and conservation practice. While some recent studies addressing uncertainty in ecology have called for accepting the limits of knowledge and the realms of non-knowledge (Beale and Lennon 2012; Ibisch et al. 2012), this paper attempts to break the unspoken assumption that "certainty is good" while "uncertainty is bad". To this end, we first illustrate cases where seeking certainty may have undesired effects. We then exemplify circumstances where uncertainty, or the attitude to it, can yield positive outcomes. Our subjectively collected examples do not attempt to provide a comprehensive coverage of the literature, but rather aim to facilitate a constructive discussion toward a new and more flexible attitude toward uncertainty. Not all examples come from the biodiversity conservation realm, but we believe that all of them have relevant implications for this field.

Perverse effects of seeking certainty

A main problem with uncertainty may be the exaggerated pursuit of certainty. Seeking certainty can pervade knowledge gathering and use, potentially leading to overconfidence, ignoring the uncertain, stagnation or inaction while awaiting stronger evidence and irresponsible behaviours originating from the seeming certainty offered by externalizing the environmental consequences of our actions. In the following, we elaborate on each of these circumstances.

Overconfidence

Overconfidence can be defined as using incomplete knowledge as if it was absolute truth. To exemplify how overconfidence relates to uncertainty, we focus on the use of simplified metrics (e.g. threshold values) for ensuring species' viability under anthropogenic pressure, or maintaining the sustainability of utilized natural resources. Identifying such thresholds is achived through a long cognitive process of simplification, including the use of models. For instance, Population Viability Analyses (PVAs) are commonly used to identify critical thresholds below which populations would collapse. PVAs employ models ranging from simple mathematical or statistical formulations, to complex, parameter-rich, individual-based models. Model outputs are then aggregated to deliver understandable and digestible (but decisive) information for decision makers, while often evicting the communication of model details, assumptions, limitations, and associated uncertainties. Policy-makers may continue the chain of simplification, e.g. by utilizing even simpler measures as elaborated below.

A first example is the concept of Minimum Viable Population size (MVP) under which populations are assumed to be non-viable. Factors affecting this value for a given species include taxonomy, life history or environmental conditions (Flather et al. 2011), yet the demand for simple rules of thumb have led some ecologists to propose that popu-

lations (of any species) "require sizes to be at least 5000 adult individuals" (Traill et al. 2007). The use of such 'magic numbers' can be misleading or even wrong (Flather et al. 2011). Another important metric is the Minimum Area Requirement (MAR), defining the minimum habitat area for a viable population. While offering policy-relevant information, especially for spatial planning, it is notable that alternative scenarios, explored within a given study, may offer MAR values differing by as much as two orders of magnitude for the same species and site (Pe'er et al. 2014b). Under such uncertainty, the MAR values finally communicated to stakeholders may reflect primarily subjective decisions.

The third example is the Maximum Sustainable Yield (MSY), which defines the largest yield (or catch) that can be removed from a stock over an indefinite period without causing a population or species' collapse (UN 1997). MSY thresholds have been long criticised for being over-simplistic (Larkin 1977), especially in the fisheries context (Quaas et al. 2013). Yet for policy-support, even simpler metrics are used that focus merely on quotas, such as Individual Fishing Quotas (IFQs) or (trophy) hunting quotas. The application of these metrics is are known ti support overfishing, driving declines in population sizes and biomass, as well as evolutionary changes in harvested species (e.g. Coltman et al. 2003; Ernande et al. 2004; Palazy et al. 2011). Overfishing further leads to marine biodiversity declines (Ye et al. 2013) and potentially even ecosystem collapses (Richardson et al. 2009). Nonetheless, these metrics remain the general norm in hunting and fisheries' policies.

These examples illustrate widely used practices in biodiversity management, where trying to reduce uncertainty can generate overconfidence or misguidance. Simple and clear metrics might ease communication between scientists and decision-makers, but can lure judgement if inadequately designed or lacking sufficient information on wildlife populations (Flather et al. 2011). At times, these values reflect nothing but guesswork (Lindsey et al 2007). In addition, a range of uncertainties remain poorly considered or communicated (Pe'er et al. 2014b). Communicated values and confidence intervals are subject to judgment interpretation, often dictated by societal aspects: thresholds that are over-restrictive may be rejected by civil society or policymakers (Pe'er et al. 2014b), promote misreporting and thereby enhance uncertainty with respect to population status (Quaas et al. 2013), or are simply posing goals that are too challenging to meet (e.g. Palazy et al. 2011; Quaas et al. 2013). These examples therefore demonstrate the perverse outcomes of a demand on scientists to support policy by maximising the (seeming) certainty with respect to the recommendations provided to policymakers. This attitude dictates the use of over-simplified thresholds, offering overconfidence rather than a true characterisation of ecological knowledge and its limits.

Ignoring the uncertain

Seeking certainty at all costs can hinder knowledge seeking and distort its interpretation, thereby slowing down the learning process. It remains an implicit goal of scientific

research to obtain 'perfect knowledge' of Earth's systems. To reach this goal, scientists simplify, transform, and aggregate evidence to identify and understand patterns and their underlying processes. Yet in the quest for understanding general patterns, the importance of outliers is often underestimated (Ibisch et al. 2012). Rare and extreme events may be exceptionally meaningful in revealing the capacities that individuals, species or ecosystems may exhibit. They are known to shape species distribution ranges and range shifts, as these are largely determined by rare long-distance dispersal events. Likewise, rapid evolutionary changes are proposed to occur during rare and rapid branching speciation events, known as "punctuated equilibrium" in evolutionary ecology (Gould and Eldredge 1993). However, because rare events are difficult to measure and analyse statistically, they remain under-explored. For instance, while PVAs frequently indicate that catastrophes and environmental stochasticity exert strong effects on simulation outcomes, a recent review could not detect an increase over time in the proportion of studies examining their effects, or the number of studies incorporating several concomitant sources of stochasticity (Pe'er et al. 2013a). PVAs therefore continue under-exploring, and likely underestimating, the impacts of rare, extreme or complex events.

Disregarding the unexpected can lead to 'black swan' situations where events that were considered highly improbable and irrelevant turn out to be both real and incurring significant impacts (Taleb 2008). In ecology, the risk of black swans emerges from the vast range of environmental processes that are either non-linear or complex, such as feedback loops leading to tipping-points (Richardson et al. 2009; Lenton 2011), extinction debt (Tilman et al. 1994) followed by a spiral of ecosystem impoverishment (Carpenter et al. 2006) or vortex of extinction (Gilpin and Soulé 1986). It is true that such processes remain difficult to analyse with current decision-making tools (Polasky et al. 2011), but compulsively targeting perfect knowledge may lead to neglecting critical evidence (Evans 2012), ignoring early warning signs, or underestimating the potential effects of such incidences (Ibisch et al. 2012). Such an attitude can further weaken the ability to reconsider current understanding, and can paradoxically support the preservation of imperfect knowledge.

Awaiting certainty as a driver of stagnation

Seeking complete certainty may delay action until strong(er) evidence can be obtained. In the meantime, however, habitat loss, fragmentation and degradation, as well as climate change, continue unabated. A prominent example of societal demand for greater certainty, accompanied by inaction, is represented by the debate over climate change, and the work of the Intergovernmental Panel on Climate Change (IPCC). Discussions over the last decades revolve primarily around two core questions: whether climate change is occurring (including speed and severity), and whether it is caused, or significantly facilitated, by anthropogenic factors such as greenhouse gas emissions (IPCC 2013). While there is by now general acceptance that global warming is taking place,

the exact contribution of humans remains under debate. Combined with uncertainties around questions of governance and best actions – namely, who should do what (e.g. Ackerman and Finlayson 2006; Bosetti et al. 2009), societies and policymakers show great resistance to take an action. The Costs of Policy Inaction (COPI; Bakkes et al. 2007), however, is likely to increase over time.

While biodiversity is affected by various forms of policy inaction in the climate change context (IPCC 2002), an example for policy stagnation with more direct relevance to biodiversity loss is the recent reform of the Common Agricultural Policy (CAP) in the European Union. Following a complex negotiation process (Rutz et al. 2013), the CAP reform failed to offer effective measures to halt ongoing declines in farmland biodiversity (Pe'er et al. 2014a). The link between agricultural intensification and biodiversity loss is well established (MA 2005; EEA 2010, 2013), and there is also growing evidence that the benefits accrued from maintaining biodiversity exceed the inclusive, long-term and larger-scale costs of losing biodiversity and ecosystem services (TEEB 2010). However, farmers and the food industry can see short-term, measurable economic gains from intensifying agricultural productivity, whereas the monetary and societal costs incurred by biodiversity loss and ecosystem degradation are complex, poorly quantified or even unquantifiable (Pe'er et al. 2014a). Consequently, arguments in favour of biodiversity conservation were either weakened by uncertainty, or put aside in face of a stronger focus on food security and food production. Retaining the CAP largely unchanged (see Rutz et al. 2013) therefore offers a good example where policy stagnation emerges, at least in part, from a societal attitude that puts higher weight on certain, short term benefits than on long-term benefits (or costs) that are associated with higher uncertainty.

A third example of how the quest for certainty can lead to stagnation is the "cautionary silence", where experts may avoid engaging in a science-policy dialogue out of the fear of making seemingly-uninformed statements (Pe'er et al. 2013b). In the case of the Norwegian Nature Index, it was paradoxically the experts "… working with the most accurate and precise population data [who] were also the ones most reluctant to use their presumably excellent expert knowledge to extrapolate beyond their observations" (Haila et al. 2014).

Personal certainty allows ignoring negative environmental effects

Environmental externalities occur when an action produces environmental costs or benefits to a third party that was not involved in the action. Externalities can be spatial, affecting different locations or acting at a larger spatial scale; or temporal, i.e., acting at a different point in time and affecting, for instance, future generations. Prominent examples for negative externalities include air, water or soil pollution, which put a range of costs on humans and the environment, usually at larger scale than the actions of single individuals; or externalization of environmental costs to poorer societies (MA 2005).

In today's globalized world, where international trade chains often put large distances between production areas and consumers, environmental externalities often occur across continents (Lenzen et al. 2012). Displacement of land-use, where land-use changes emerge from consumption elsewhere, largely acts from high-income to low-income countries while putting pressure on ecosystems in the latter (Weinzettel et al. 2012). Lenzen et al. (2012) estimated that 30% of red-listed species are threatened due to internationally traded commodities like coffee, tea, sugar, textiles or fish. One might argue that end-consumers may not be aware of the negative environmental consequences of their action, partly due to complex causal relationships (Hertwich 2012). However, it can also be asserted that consumers often act under the assumption of "personal certainty" regarding their own security. Globalization of markets and externalization of environmental costs render consumers, especially in high-income countries, immune to the (immediate) consequences of their consumption attitudes. Resource shortage or price fluctuations can be easily buffered at the consumer level by shifting markets, but can generate poverty or local food-scarcity at the area of production, often located in low-income countries. The certainty that one's actions will not expose oneself to environmental or societal costs, thereby promotes unsustainable or even irresponsible behaviours.

A local scale example in which personal security can lead to unsustainable behaviour is risk avoidance offered by insurance. In dryland pastoral systems, where environmental uncertainty is an inherent property of the ecosystem, farmers historically developed approaches such as mobility, reliance on social networks for building up herds after catastrophic events, and setting aside open grasslands as grazing reserves for emergency times (Müller et al. 2011). Apart from their usefulness to deal with uncertainty (with respect to income), these strategies often have positive ecological and social by-effects. Nowadays, farmers can reduce their risks by contracting insurances, which compensate them in the case of reduced rainfalls below a certain level. Reducing the economic risks, however, replaces the necessity for ecosystem-based buffers. This potentially leads to a modification in farmers' behaviour, up to abandoning traditional sustainable strategies such as the protection of parts of the pasture in rainy years to use it as a reserve for dry years (Müller et al. 2011).

These examples demonstrate that, across scales, seeming certainty offered by externalizing environmental costs may promote irresponsibility or unsustainable practices – thus laying the foundations of the tragedy of the commons (Hardin 1968, Ostrom 1999, 2009).

Positive outcomes of uncertainty

In the following sections we offer illustrative examples of circumstances where uncertainty, or the attitude to it, can yield positive outcomes: driving improvements in knowledge, promoting cautious actions, enhancing a more flexible and adaptive societal behaviour, raising public awareness and engagement in nature conservation, enhancing cooperation, and promoting communication.

Driver for improving knowledge

Research is driven by the quest for improved understanding and certainty in knowledge. Yet one could also assert that science and scientists thrive on uncertainty: open questions make the world interesting and exciting, and motivate our quest for knowledge. Uncertainty not only guides the starting point of learning processes, but is also a key element at the closing of learning iterations. Descartes' "philosophy of the doubt", upon which science still greatly relies, does not build on removing uncertainty but rather on clearly identifying it en-route to so-called "perfect knowledge" (Descartes 1637). This entails identifying gaps, imprecision, inaccuracy, or any weakness associated with the process of understanding; excluding all questionable beliefs in the pursuit of scientific truth; and, at the end of any learning step, explicitly identifying and acknowledging the remaining uncertainty. Thereby, one obtains relevance and confidence in the outcomes of the scientific exploration, compared to leaving uncertainty inextricable.

Promoting caution in action

Uninformed decisions taken by policy-makers and decision-makers could result in long-term risks to humans, the environment, or both. Insufficient scientific evidence could, in such cases, promote cautious and responsible actions if a precautionary approach is taken (see also Haila et al. 2014). Specifically, the precautionary principle has the power to promote decisions on the basis of uncertainty itself: to this end, it is required to a) use currently available data, b) indicate uncertainty, c) identify potentially adverse effects and d) evaluate the potential consequences of inaction (EC 2000). The precautionary principle hence enables avoiding policy inaction when knowledge is insufficient. It explicitly adopts an attitude that accommodates uncertainty into decision making and "…enables rapid response in the face of a possible danger to human, animal or plant health…" (EC 2000). This principle is well established in the European Union's law, including the Habitats Directive, and was adopted by the Convention on Biological Diversity (CBD 2004). A particularly interesting examination of the precautionary principle in biodiversity conservation relates to ecological restoration: restored ecosystems might prevent or reduce the impacts of environmental catastrophes (Wiegleb et al. 2013). The precautionary principle hence demonstrates that an alternative attitude to uncertainty can promote both reactive and proactive conservation actions.

Promoting societal flexibility, responsiveness and adaptability

Social acceptance of unknowns may allow societies to stay attentive to early warning signs, and maintain sufficient conceptual and practical flexibility for an effective re-

sponse. It may reduce the risks of disregarding "black swans", as societies may be better prepared to accept that the unexpected is likely to occur in a period of unforeseen, rapid changes. It may further allow quick adoption of alternative reaction paradigms, should current ones fail (Carpenter et al. 2006; Polasky et al. 2011). In conservation practice, an example of a more flexible decision-making process is the employment of adaptive management, defined as "an iterative decision-making process under uncertainty that is designed to learn and incorporate new information and thereby improve future decision-making" (Polasky et al. 2011). This approach views management decisions as experiments, whose impacts need to be tested, monitored and assessed within a "learning by doing" process (Keith et al. 2011; Westgate et al. 2013; Haila et al. 2014). Adaptive management can gain from embracing uncertainty, as this entails viewing learning in a positive light, and welcoming the opportunity to experiment.

Raising public awareness and engagement

Uncertainty can be used to call for conservation actions, with direct benefits for species as well as promoting public awareness and engagement. Particularly, risks of species' extinction often confront scientists and practitioners with a conflict known as "Noah's Arch dilemma": which species should we save first? (Scott and Csuti 1997; Higgins et al. 2004; Perry 2010). Different conservation schools suggest we should maximise the number of species to be protected (Wilson et al. 2011), safeguard irreplaceable ecological functions (Perry 2010), or seek to maximise cost-effectiveness of conservation efforts in light of uncertainty (Salomon et al. 2013). By contrast, translocations, reintroductions and assisted colonisations of focal threatened species are characterised by high costs and low chances of success. Nonetheless, they receive strong societal support and substantial investments (Fischer and Lindenmayer 2000; Armstrong and Seddon 2008). Such efforts face various uncertainties, due to limited knowledge, high stochasticity, and little room for mistakes. One can justify such efforts by ethical arguments, the importance of specific cultural services provided by such species (Mech 1995) or their key contribution to the functioning of ecosystems. Yet note that the appeal of such actions lies especially in spectacular success stories, where species were rescued from extinction from just a few remaining individuals. Some prominent examples are the Arabian Oryx (Stanley-Price 1989), Californian condor (Walters et al. 2010), Przewalski horse (Boyd and Houpt 1994), wisent (Tudge 1992) and Persian Fellow deer (Bar-David et al. 2005).

The relation of such successes to uncertainty can be viewed in two ways. First, on the choice between uncertain chances to save a species versus high risk of extinction if no action is taken, the choice for uncertainty is a choice for hope. Secondly, the natural uncertainty around such emergency actions, and the ambition behind them, help raising public attention, awareness and engagement, and attracts important funding to nature conservation. Hence, uncertainty can be an important driver of action in situations where inaction could lead to irreversible, undesired losses.

A driver of cooperation

Uncertainty can enhance, or even drive, cooperation among animals and humans alike. Theories on the evolution of sociality have long suggested that resource scarcity or unpredictability, or enhanced risks for individuals, can be key drivers toward cooperation (Cohen 1966; Lin and Michener 1972; Frank and Slatkin 1990; Jetz and Rubinstein 2011). While some recent studies demonstrated that resource scarcity or unpredictability (e.g. in relation to climate change) can enhance conflicts and violence among humans (Le Billon 2001; Hsiang et al. 2013), other, less prominent studies point out that resource variability can also promote cooperation (Bogale and Korf 2007; McAllister et al. 2011). An interesting example on the emergence of cooperation examined local versus large-scale social conflicts originating from heterogeneity in wealth and resources (Abou Chakra and Traulsen 2014). This study examined social dilemmas with tension between individual incentives to optimize personal gain versus social benefits. An additional cause of conflict was the uneven allocation of resources between rich and poor. Using a simulation model which assumes a collective-risk dilemma, Abou Chakra and Traulsen (2014) found that enhanced uncertainty may lead to increased cooperation where the rich assist the poor. However, the poor contributed only when early contributions were made by the rich players. This study therefore points out that uncertainty can indeed lead to cooperation, even at large scales, but this requires that relevant players acknowledge their responsibility for this to happen. This example warrants attention in the context of the global biodiversity crisis, because global hotspots of biodiversity and its loss are concentrated especially in low-income countries (Myers et al. 2000).

Promoting communication and trust

In the scientific world, explicit consideration of limitations promotes credibility when communicating knowledge. In the same way that a scientific paper gains credibility by explicitly discussing its limitations, scientists communicating their knowledge to the public are anticipated to exhibit honesty with respect to uncertainty. This is well exemplified through the "ClimateGate" event: internal discussions over uncertainty, which were not communicated transparently, have eased the case for those seeking to distrust the work of the IPCC (van der Sluijs et al. 2010; Ravetz 2011; Garud et al. 2014). Ravetz (2011) suggested three main take-home messages from this incident: "1) quantify uncertainty, 2) building scientific consensus [...and retain] 3) openness about ignorance". Garud et al. (2014) suggested that the tension between "normal science" - as perceived by scientists - and "post-normal science" constellations, where high stakes meet high uncertainty, requires an alternative approach altogether. Accordingly, the fourth assessment of IPCC has indeed adopted a new approach to uncertainty, where comments are documented and dealt with in a completely transparent way (IPCC 2013).

Discussion

Using some illustrative examples, we have shown that seeking to reduce uncertainty by all means can produce a range of adverse outcomes, including oversimplification and overconfidence, or policy stagnation due to awaiting greater certainty. On the other hand, accepting and embracing uncertainty can have positive impacts such as favouring cautionary actions, flexible solutions, greater cooperation and transparent communication.

As our focus is biodiversity conservation, many examples focus on conflicts between humans and nature, and involve uncertainties originating from the complexity of integrating the interests of multiple actors. While predictive ecology continues to evolve towards better understanding of such dynamic processes (Evans 2012), our understanding of socio-ecological systems is only starting to develop, and the field retains, and will likely continue retaining, large degrees of unpredictability (Walker and Salt 2006; Scheffer et al. 2009; Polasky et al. 2011).

A range of novel approaches can now integrate multiple sources of uncertainty, offering promising frameworks to aid policy-makers and practitioners in defining effective strategies and solutions under uncertainty. These include decision theory and scenario-planning (reviewed by Polasky et al. 2011; Grechi et al. 2014; Knights et al. 2014), as well as the approaches proposed within the realms of post-normal science (Ravetz 2004; Francis and Goodman 2010).

Notwithstanding, biodiversity research still focuses primarily on reducing Type 1 errors: failing to reject a wrong hypothesis (Schneider 2006). This entails a strong preference for reducing uncertainty. Decision makers, by contrast, are usually more concerned about committing Type 2 errors, namely, rejecting a correct hypothesis (Schneider 2006), probably because their governance responsibilities make them more prone to avoid taking decision only if risks might exceed acceptable thresholds. This creates a dichotomy where scientists may adopt a "precautionary silence" while awaiting better evidence, whereas policy-makers continue taking decisions within a "business as usual" framework. Such dynamics maintain or even increase the pressures on biodiversity. We therefore assert that the dominating certainty paradigm brings researchers, practitioners, decision-makers and the public alike to share the common assumption that ecological research can, and should, support policy by seeking to reduce uncertainty. Thereby, we maintain overconfidence and policy stagnation, discard of early-warning signs, or adopt irresponsible behaviours. We see this attitude as unnecessary because policymakers are surely aware of, and obviously accept, uncertainty in other fields. For example, economic decisions and negotiation processes not only incorporate and accept uncertainty, but often even maintain it deliberately in order to allow some freedom in interpretation or implementation. An alternative is therefore to enhance the acceptance, by all parties, that biodiversity research and conservation act largely in the realms of uncertainty. We do not perceive such an alternative attitude as a replacement to the quest for knowledge and certainty, but as an expansion of the range of potential responses to uncertain conditions.

Implications across scales

The need for a new attitude to uncertainty can be demonstrated across scales, from local to global. Locally, adaptive management is already mentioned by thousands of ecological studies, yet surprisingly few really adopt this principle, and even fewer can show documented successes (Westgate et al. 2013). Among the key reasons are insufficient monitoring, and insufficient addressing of social aspects (Westgate et al. 2013). These challenges indicate that, for adaptive management to become successful, a change in attitude to uncertainty is needed among all parties.

At larger scales, the precautionary principle has only rarely been successfully applied in biodiversity conservation, partly due to the lack of sufficient guidance to move from awareness to implementation (Tisdell 2011; Kanongdate et al. 2012; Rayfuse 2012). Greater acceptance of uncertainty and its implications would likely reduce the risk of societal resistance if the principle is used.

Global efforts to understand and address the biodiversity crisis, especially through the evolving Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), need to tackle key questions on how to scale up ecological processes, pressures and solutions from local to global. Scaling up, however, entails propagation of uncertainty. Standing issues include the relationship between biodiversity and ecosystem services (Balvanera et al. 2014); the multitude of drivers acting across scales (MA 2005; Tzanopoulos et al. 2013); complex production-consumption chains (Hertwich 2012; Lenzen et al. 2012); and rapid political and socioeconomic changes, within which responsibilities need to be identified and decisions made. How IPBES will accommodate uncertainty in its decision making processes, thus remains an open and important question to resolve (Koetz et al. 2012; Pe'er et al. 2013b; Balvanera et al. 2014).

Developing an alternative attitude to uncertainty could start among scientists, acknowledging and communicating that the field of biodiversity research largely lies in the realms of uncertainty and therefore the demand for high confidence cannot always be fulfilled. Yet the fix of environmental decision-making on confidence intervals and significance levels, cannot be broken by scientists alone: it requires that stakeholders learn to accept a diversity of knowledge and non-knowledge inputs into the science-policy and science-society dialogue. In the process, the nature of the dialogue itself may change.

A cautionary point

While the main goal of this paper is to promote a broader range of attitudes to uncertainty, we do not wish to suggest that uncertainty should be always perceived as positive or welcome. There are numerous cases where uncertainty is clearly undesired, both in terms of associated risks and negative societal responses to it. A particular reason for caution should be given to circumstances where stakeholders or parties benefit from uncertainty or use it to achieve own goals. While in biodiversity conservation research

we are only starting to understand the different aspects of uncertainty, other fields, e.g. economics, politics, or insurance, have gained far more experience in this area. Thus, how we deal with (and communicate) uncertainty may need caution depending on circumstances and parties involved. However, there are plenty of opportunities for learning.

Outlook

This paper focused on subjectively-collected examples to bring about a specific opinion. While we did not attempt to offer a comprehensive coverage of such cases, we recognize a need for an extended review. Elements of such a review would include mapping circumstances in which certainty, versus uncertainty, may promote or impede effective management of natural resources. A meta-analysis or quantification of the impacts could thus direct a better "choice of attitude" towards different forms of uncertainty.

To make these alternative attitudes operational in biodiversity conservation, it could also be desirable to examine attitudes toward uncertainty within legislative or judiciary frameworks in different parts of the world. For instance, it is worthy to explore differences between the European Union and the United States of America in terms of evidence-provision in court (i.e. respectively inquisitorial vs adversarial (Froeb and Kobayashi 2001)), or compare the precautionary principle, which is generally adopted by the EU, against the "burden of proof" approach applied in North America. The way uncertainty affects legislative systems may reflect the general attitude of societies to it. Better understanding of this relation may aid in developing operational alternatives in biodiversity practice.

Finally, we call for stronger trans-disciplinary research on the feedbacks between societal and scientific components in decision-making – e.g. in terms of "cost effective" or "best" conservation efforts given societal perception of "success". While we did not explore in depth any economic criteria for decision-making, one should acknowledge that it is primarily in economy that multi-dimensional approaches are adopted to address multiple sources of uncertainty. These are already increasingly adopted in ecological decisions in consideration of the societal sphere (Schneider et al. 2000; Polasky et al. 2011), as well as in analyses of trade-offs between competing decisions under uncertainty (Chee 2004; Stewart and Possingham 2005; Carwardine et al. 2010; TEEB 2010). Building on the experience gained through such studies, an iterative feedback process could be achieved between facilitating the development of alternative attitudes towards uncertainty, and integrating them into the science-policy dialogue.

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